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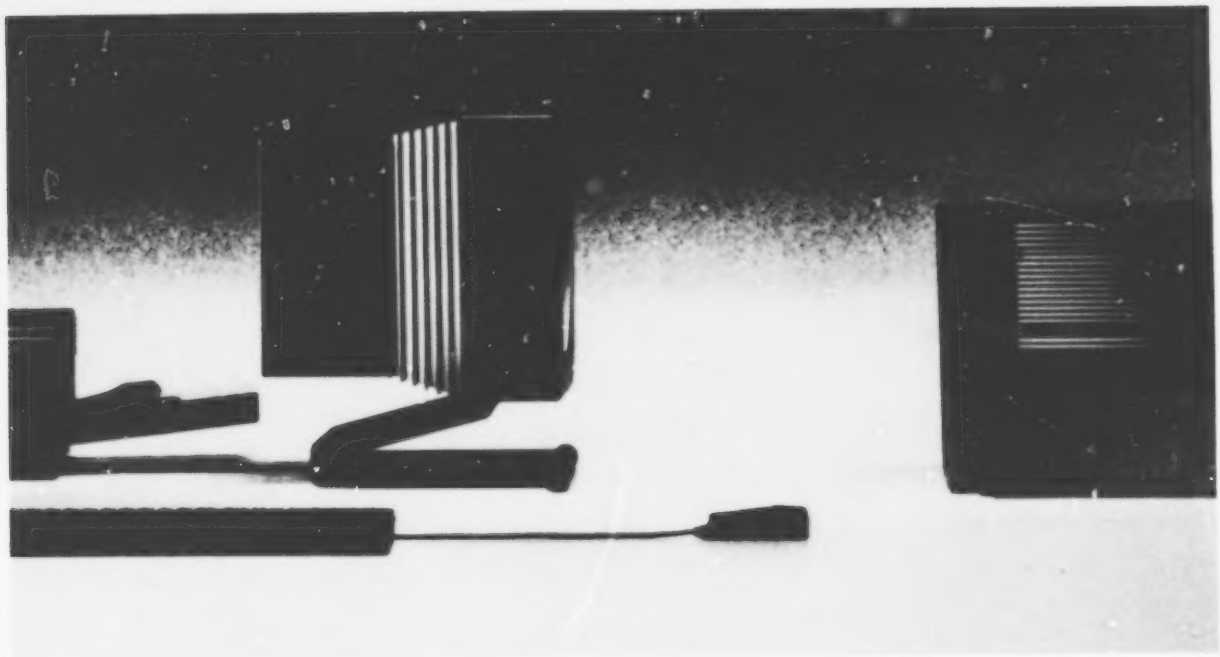

MAGNESIUM AND MAGNESIUM COMPOUNDS

By Deborah A. Kramer

1989

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

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MAGNESIUM AND MAGNESIUM COMPOUNDS

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October 1990

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COVER PHOTO:
Computers have become a growing application for magnesium metal because of its light weight and built-in resistance to electromagnetic interference. The computer shown has a die-cast magnesium cube housing the central processing unit. (Photo is courtesy of the International Magnesium Association.)

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MAGNESIUM AND MAGNESIUM COMPOUNDS

By Deborah A. Kramer

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MAGNESIUM

Domestic magnesium production hit its highest level since the beginning of the decade because strong demand continued for magnesium for aluminum alloying, casting applications, and iron and steel desulfurization. Because demand could not be completely met with primary production, particularly in the first half of the year, inventory levels dropped rapidly to reach a 20-year low by midyear. Demand slowed in the second half of 1989, and producers replenished their stocks. Magnesium exports increased significantly, and imports declined from the high level in 1988. The United States remained a net exporter of magnesium.

World production of magnesium reached a record-high level in 1989, and production capacity was expected to increase significantly within the next year. Two new plants in Canada planned to bring a total of 52,500 metric tons of annual capacity on-stream in 1990, and a small capacity expansion was planned in Brazil. Preliminary investigations were underway to construct new primary magnesium plants in Australia, Colombia, India, Norway, and the Republic of South Africa.

Legislation and Government Programs

In September, the Environmental Protection Agency issued a final ruling on the criteria to evaluate mineral processing wastes for exclusion from regulation under subtitle C of the Resource Conservation and Recovery Act (RCRA). Wastewater from the anhydrous process for magnesium recovery was a candidate for exclusion under the original criteria in 1988. This waste passed the high-volume, low-toxicity criteria established in the final ruling and was conditionally excluded under RCRA. Final subtitle C regulation of the process wastewater was to be determined by January 1990.[1]

Production

U.S. primary magnesium production was at the highest level since 1980 and was at 95% of rated yearend capacity. In April, AMAX Magnesium Corp. announced that it had sold its Rowley, UT, facility, but the sale was not finalized until September. Renco Group Inc. purchased the primary magnesium plant, which was renamed Magnesium Corp. of America (MagCorp). MagCorp planned to increase its capacity to 38,000 tons in 1990. The company also began drawing brine in 1989 from its new solar ponds in the west desert that replaced the solar ponds destroyed in a 1986 flood of the Great Salt Lake. MagCorp estimated that the new ponds have a 10- to 15-year supply of brine.

In May, Dow Chemical Co. announced that annual capacity at its Freeport, TX, magnesium plant was increased by 5,000 tons to 90,000 tons. This represented the fourth capacity increase at the facility since late 1987. The capacity increase was in response to low stock levels and growing demand in the automotive diecasting and desulfurization sectors. Dow's three previous capacity increases involved restarting idled electrolytic cells, but the fourth increase involved improvements in the production process.

Northwest Alloys Inc., a subsidiary of Aluminum Co. of America (Alcoa), planned to increase magnesium production at its Addy, WA, plant by

TABLE 1

SALIENT MAGNESIUM STATISTICS

(Metric tons unless otherwise specified)

	1985	1986	1987	1988	1989
United States:					
Production:					
Primary magnesium	135,728	125,639	124,396	141,983	152,066
Secondary magnesium	41,298	41,807	45,164	50,207	51,200
Exports	36,580	39,909	44,182	49,802	56,631
Imports for consumption	8,411	8,355	10,851	14,407	12,289
Consumption, primary	r83,752	r78,961	r94,620	100,793	105,226
Price per pound	$1.48-$1.53	$1.53	$1.53	$1.58-$1.63	$1.63
World: Primary production	r325,183	r322,408	323,930	p334,372	e343,548

eEstimated. pPreliminary. rRevised.

making proprietary improvements in its processing methods. Reportedly, two-thirds of Northwest Alloys' production is used by Alcoa for aluminum alloying. Alcoa used to purchase all of Northwest Alloys' production, but although aluminum can production has increased significantly, increased recycling rates have lowered Alcoa's consumption of primary magnesium.

Consumption

Spectrulite Consortium Inc. purchased Dow's magnesium rolled products business citing the need to strengthen the company's market position. In past years, Dow had purchased Spectrulite's rolled products, and Spectrulite also supplied Dow with extrusion billet for Dow's operations in Aurora, CO.

Frontier Foundries Inc. opened a new magnesium investment casting facility in its complex in Titusville, PA. The company's investment casting process can produce castings with precise size tolerance, smooth surface finish, and intricate detail. Also, Thompson Castings Inc. announced the development of a new casting process that yields near-net-shape prototype components for automotive testing requirements. Components can be produced in a wide variety of shapes and in sizes from a few ounces to a few pounds. Castings can be produced by the new process with interlocking cores with thin-wall passages for pneumatic and hydraulic components.

Several new applications for die-cast magnesium in the automotive industry were announced. The Cadillac Motor Div. of General Motors Corp. planned to substitute magnesium valve covers for aluminum on the V-8 engines used in most of its cars. Also, magnesium was planned to be used for the main structural front seat parts in the 1989 Mercedes Benz SL Roadster, for Audi's V-8 die-cast instrument panel, and for wheels in some of Honda Motor Corp.'s automobiles. A review of magnesium applications in the automotive industry outlined additional uses.[2]

Usage of magnesium continued to increase in the computer industry for both die-cast and extruded components in housings and internal applications. Because computer components change more quickly than those in other industries, extrusions may be preferable to castings. Extrusions have relatively low-cost tooling and economical short-run capabilities compared to diecasting, although the secondary costs may be higher.[3]

Stocks

Consumer stocks of primary magnesium declined from 6,860 tons at yearend 1988 to 5,350 tons at yearend 1989. Magnesium alloy ingot stocks increased slightly from 838 tons at yearend 1988 to 849 tons at yearend 1989.

Producers' primary magnesium stocks declined to their lowest level in nearly 20 years by the end of the second quarter. However, by the end of the year, stocks increased substantially to 20,133 tons and also increased from yearend 1988 stocks of 17,087 tons.

Prices

Producers' quoted magnesium prices were unchanged during 1989. Both Dow and MagCorp quoted a price for primary metal ingot at $1.63 per pound

TABLE 2

MAGNESIUM RECOVERED FROM SCRAP PROCESSED IN THE UNITED STATES, BY KIND OF SCRAP AND FORM OF RECOVERY

(Metric tons)

	1985	1986	1987	1988	1989
KIND OF SCRAP					
New scrap:					
Magnesium-base	1,510	991	845	2,641	3,951
Aluminum-base	16,252	17,822	20,867	19,926	19,278
Total	17,762	18,813	21,712	22,567	23,229
Old scrap:					
Magnesium-base	4,630	3,958	3,857	3,882	4,269
Aluminum-base	18,906	19,036	19,595	23,758	23,702
Total	23,536	22,994	23,452	27,640	27,971
Grand total	41,298	41,807	45,164	50,207	51,200
FORM OF RECOVERY					
Magnesium alloy ingot [1]	3,838	3,925	4,001	3,930	4,494
Magnesium alloy castings	438	551	447	438	795
Magnesium alloy shapes	—	31	—	1,065	635
Aluminum alloys	35,797	37,293	40,711	43,827	43,125
Zinc and other alloys	8	3	W	W	W
Chemical and other dissipative uses	3	W	W	943	W
Cathodic protection	1,214	W	—	W	W
Total	41,298	41,807	45,164	50,207	51,200

W Withheld to avoid disclosing company proprietary data; included in "FORM OF RECOVERY: Total."
[1] Includes secondary magnesium content of both secondary and primary alloy ingot.

TABLE 3

U.S. CONSUMPTION OF PRIMARY MAGNESIUM, BY USE

(Metric tons)

Use	1985	1986	1987	1988	1989
For structural products:					
Castings:					
Die	2,229	3,646	3,710	4,383	5,627
Permanent mold	825	748	1,121	943	811
Sand	1,482	1,373	1,454	1,743	1,017
Wrought products:					
Extrusions	7,036	6,285	6,804	6,907	6,712
Other[1]	3,804	3,938	3,884	5,719	5,326
Total	15,376	15,990	16,973	19,695	19,493
For distributive or sacrificial purposes:					
Alloys:					
Aluminum	37,059	36,804	49,784	51,183	51,436
Other	7	5	8	7	9
Cathodic protection (anodes)	4,307	6,342	5,537	6,234	5,474
Chemicals	3,469	1,449	1,047	780	594
Iron and steel desulfurization	e8,000	e9,000	e10,000	W	10,463
Nodular iron	1,540	1,622	1,811	2,037	1,635
Reducing agent for titanium, zirconium, hafnium, uranium, beryllium	7,372	5,235	5,286	8,467	10,798
Other[2]	6,622	2,514	4,174	12,390	5,324
Total	r68,376	r62,971	r77,647	81,098	85,733
Grand total	r83,752	r78,961	r94,620	100,793	105,226

eEstimated. rRevised. W Withheld to avoid disclosing company proprietary data; included in "Other."
[1]Includes sheet and plate and forgings.
[2]Includes scavenger, deoxidizer, and powder.

TABLE 4

U.S. STOCKS AND CONSUMPTION OF NEW AND OLD MAGNESIUM SCRAP[1]

(Metric tons)

	Stocks, Jan. 1	Receipts	Consumption			Stocks, Dec. 31
			New scrap	Old scrap	Total	
1988	960	5,610	1,901	3,882	5,783	787
1989	787	7,233	3,052	4,269	7,321	699

[1]Cast scrap, solid wrought scrap, borings, turnings, and drosses.

and diecasting alloy price at $1.43 per pound throughout the year. A compilation of U.S. magnesium prices from 1915 to 1988 was published by the Bureau of Mines.[4]

Foreign Trade

Because of implementation of the Harmonized Tariff System (HTS) beginning in 1989, trade data for 1989 may not be comparable with those of previous years. Exports of magnesium increased significantly compared with those in 1988. The Netherlands, 27%; Canada, 24%; and Japan, 21%, were the principal destinations for U.S. exports. Magnesium imports declined from the high level in 1988. Norway was the source of 51% of domestic imports, mainly primary metal and alloy. Canada supplied 32%, mainly waste and scrap, and Mexico supplied 9% of U.S. imports.

World Review

World primary magnesium production reached a record-high level in 1989, and world inventory levels dropped significantly during the year. According to the International Magnesium Association, world inventories dropped to a 5-year low in June, but recovered to end the year at 35,000 tons. Yearend stocks represented 52 days of average daily demand during 1989 and were 7,800 tons above those at yearend 1988.

Australia.—Queensland Metals Corp. announced that it was seeking a partner to construct a 60,000-ton-per-year primary magnesium plant in Gladstone. The company was developing a magnesite mine and magnesia production plant nearby and expected to use magnesite for the metal plant feed material.

Brazil.—Cia. Brasileira do Magnesio S.A. (Brasmag) reportedly received a $10 million loan from a pool of regional banks to increase its annual primary magnesium capacity to 10,600 tons in 1990. The expansion included installation of a series of electric-reduction vacuum furnaces. Brasmag planned to increase production capacity further in the mid-1990's if the Government approves the company's proposal to construct its own hydroelectric powerplant. When the initial expansion is completed, Brasmag plans to export one-fourth of its production

TABLE 5

U.S. EXPORTS AND IMPORTS FOR CONSUMPTION OF MAGNESIUM

Year	EXPORTS							
	Waste and scrap		Metal		Alloys (gross weight)		Powder, sheets, tubing, ribbons, wire, other forms (gross weight)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989	1,406	$3,286	43,233	$123,509	3,849	$15,495	8,143	$28,084
	IMPORTS FOR CONSUMPTION							
	Waste and scrap		Metal		Alloys (magnesium content)		Powder, sheets, tubing, ribbons, wire, other forms (magnesium content)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989	3,773	$7,856	3,879	$12,373	3,829	$14,702	808	$2,928

Source: Bureau of the Census.

to Mexico and other Latin American countries; the bulk of the magnesium is planned for domestic consumption. Brazil's magnesium consumption, mostly from the automotive industry and estimated to be 9,600 tons in 1988, was partially met with imported metal.

Canada.—Small-scale magnesium production at Norsk Hydro A/S's Becancour, Quebec, plant began in November. The company planned to reach the plant's full production capacity of 40,000 tons per year by the first quarter of 1990. Total construction costs were about $180 million greater than the $340 million originally budgeted. Included in the total investment were the costs necessary to expand gradually the plant's annual capacity to 60,000 tons.

In November, Magnesium Co. of Canada Ltd. (MagCan) announced the startup of 12,500 tons of annual capacity at its new magnesium plant in High River, Alberta, would be delayed until January 1990. The company cited problems in getting the necessary labor to complete plant construction. MagCan planned to add two 25,000-ton-per-year capacity increments to reach a total annual capacity of 62,500 tons by 1994.

Colombia.—Industrial Minera de Colombia was seeking foreign partners to share the construction costs for a $200 million magnesium complex in the Guajira peninsula. Annual production of the proposed electrolytic plant would be 30,000 tons. In addition to the electrolytic plant, the magnesium complex would include a desalination facility, limestone mine, powerplant, and chlorine gas and caustic soda plant.

India.—Ispat Alloys Ltd. announced that it would construct a 4,000-ton-per-year primary magnesium plant near Agartala, Tripura, at a cost of about $37.5 million. This area is rich in dolomite and natural gas, both necessary for operating a silicothermic plant. Annual demand for magnesium in India was estimated to be about 2,000 tons. No timetable was set for plant construction.

Japan.—In February, Nichiju A.M. announced an increase in its annual magnesium production by 1,200 tons to 4,800 tons at its plant in Takaoku, Toyama. In addition, Ube Industries Ltd. announced that it would increase magnesium production at its plant in Ube City to 8,000 tons per year by mid-1989. Ube planned to restart idled furnaces to achieve the additional production because all the company's operating furnaces were at capacity. With the closure of Furakawa Magnesium Co. Ltd.'s Oyama City, Tochigi, plant in March, total magnesium production capacity in Japan was 13,000 tons by yearend.[5]

Norway.—Norsk Hydro announced that it would close 10,000 tons of annual magnesium production capacity at its Porsgrunn complex when its Canadian plant comes on-stream. The closure was announced late in the year after Norsk Hydro reported that annual production capacity at the plant had been increased by 3,000 tons to 51,000 tons. The incremental increase was achieved by channeling additional electric power through existing facilities. Capacity that was closed in 1988 because of environmental problems was expected to remain closed for at least 5 years.

Elkem A/S planned to build a 20,000-ton-per-year primary magnesium plant if it could come to terms with the Government on electrical supplies. Elkem would take advantage of a power-rate cut offered to a new power-intensive industry. Two economically depressed cities, Fauske and Mo i Rana, were considered as possible plant sites.

South Africa, Republic of.—Anglo American Corp. reportedly began a feasibility study on recovering magnesium from a dolomite deposit in the Transvaal. The dolomite would be used to feed a 10,000-ton-per-year plant operated in a joint venture between Anglo American and Cape Lime Corp., the owner of the dolomite deposit.

United Kingdom.—Norsk Hydro reportedly acquired a majority share of Kirk Precision Ltd., a manufacturer of magnesium bicycle frames, and planned to establish a robotic facility capable of producing 200,000 frames annually. Kirk Precision was believed to have the largest hot-chamber, high-pressure diecasting machinery in existence. This machinery may be adaptable for production of large magnesium diecastings for other applications, particularly in the automotive industry.[6]

TABLE 6

U.S. EXPORTS OF MAGNESIUM, BY COUNTRY 1989

Country	Waste and scrap		Metal		Alloys (gross weight)		Powder, sheets, tubing, ribbons, wire, other forms (gross weight)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Argentina	—	—	483	$1,652	—	—	26	$136
Australia	—	—	2,143	6,871	—	—	215	915
Austria	29	$65	51	169	—	—	—	—
Bahrain	—	—	125	356	—	—	—	—
Belgium	—	—	1	17	—	—	159	705
Brazil	152	397	811	2,534	1	$4	496	1,685
Canada	48	129	7,225	17,254	1,410	5,615	4,906	13,135
China	—	—	199	698	—	—	—	—
Colombia	—	—	10	38	9	32	47	206
France	—	—	22	331	—	—	(1)	17
Germany, Federal Republic of	18	37	—	—	1,209	5,229	135	792
Ghana	—	—	279	960	—	—	—	—
Hong Kong	—	—	(1)	5	21	36	1	13
India	—	—	508	1,829	5	196	1	24
Ireland	—	—	—	—	—	—	—	—
Italy	73	205	73	1,255	17	80	14	264
Japan	42	70	11,233	32,701	157	714	647	3,490
Korea, Republic of	33	89	838	2,563	193	1,062	141	629
Mexico	925	2,079	989	3,209	99	319	357	807
Netherlands	21	43	14,990	39,522	164	477	394	1,207
New Zealand	—	—	65	246	—	—	2	142
Norway	—	—	1,211	3,485	2	5	—	—
Peru	—	—	24	95	—	—	—	—
Singapore	—	—	—	—	20	66	(1)	5
South Africa, Republic of	—	—	98	331	35	119	88	509
Spain	—	—	738	2,446	—	—	—	—
Sweden	—	—	42	395	(1)	4	21	119
Taiwan	—	—	512	1,692	20	68	44	123
Turkey	20	40	—	—	—	—	—	—
United Kingdom	19	41	202	1,171	30	126	124	1,526
Venezuela	17	70	61	133	—	—	228	767
Other	9	21	300	1,551	457	1,343	97	868
Total	1,406	3,286	43,233	123,509	3,849	15,495	8,143	28,084

[1] Less than 1/2 unit.

Source: Bureau of the Census.

Current Research

Mintek, of the Republic of South Africa, patented a process to produce magnesium in a plasma-arc furnace. In the new process, a plasma-arc furnace replaced the submerged-electrode furnace normally used in the Magnetherm process, and the process was done at atmospheric pressure rather than under a vacuum. The reaction, in which magnesium vapor is generated from dolomite and ferrosilicon, was the same as that of the Magnetherm process. Mintek claimed that capital costs for the new process were less than those for the Magnetherm process, and it could be adapted to continuous or semicontinuous operation.[7]

Magnesium Elektron Ltd. introduced a magnesium casting alloy, designated WE43, a high-strength alloy containing yttrium for use at temperatures up to 300° C. The alloy was cast by a novel process called differential-pressure sand casting, which provides thin-walled castings with improved properties and increases metal utilization. Corrosion resistance of WE43 was reported to be comparable with that of high-strength aluminum alloys. Potential applications for WE43 are aerospace engines, helicopter transmissions, and missiles. Allied-Signal Inc. also developed a new magnesium casting alloy suitable for applications in the aerospace and automotive industries. The magnesium-aluminum-zinc-neodymium alloy was reported to match the corrosion resistance of 2024 aluminum alloys. It also

TABLE 7

WORLD ANNUAL PRIMARY MAGNESIUM PRODUCTION CAPACITY,[1] DECEMBER 31, 1989, BY CONTINENT AND COUNTRY

(Metric tons)

	Capacity
North America:	
United States	160,000
Canada	9,000
Total	169,000
South America: Brazil	6,000
Europe:	
France	14,000
Italy	10,000
Norway	51,000
U.S.S.R.	95,000
Yugoslavia	6,000
Total	176,000
Asia:	
China	9,000
Japan	13,000
Total	22,000
World total	373,000

[1] Includes capacity at operating plants as well as at plants on standby basis.

showed superior resistance to pitting, compared with conventional magnesium casting alloys, while retaining equivalent mechanical properties. The new alloy can be formed by rapid-solidification-processing techniques.

A new company, Thixomat Inc., was formed to commercialize a process to fabricate near-net-shape metal and metal-matrix composite parts. The process, developed by Dow, combines elements of diecasting with injection molding, and developmental work was done with magnesium alloys and magnesium metal-matrix composites. In the one-step patented process, granules of magnesium alloy were fed into a reciprocating-screw-injection system, heated to 580° C to form a semisolid slurry, and injected quickly into a mold. Components produced from thixotropic magnesium were reported to have 50% lower porosity and greater dimensional stability than die-cast components.[8]

Outlook

The International Magnesium Association, in its annual review of magnesium supply and demand, projected an average annual growth rate in consumption of 3% from 1989 to 1993 throughout market economy countries. Most of this growth was projected to occur in North American diecasting applications, with all other applications exhibiting small growth. Continued recycling of aluminum beverage cans, the largest market for magnesium, coupled with reduced can weight, contributed to a slow growth forecast in this application. But, if aluminum food cans are proven technically feasible and aluminum beverage cans are accepted in Europe, the slow growth forecast could change dramatically.

Worldwide magnesium production was expected to increase over the same period, but as significant additional capacity comes on-stream in Canada, capacity utilization was expected to decline. As part of the decrease in capacity utilization, higher cost magnesium producers were expected to take small capacity increments offline when inventories increase to an acceptable level.[9]

MAGNESIUM COMPOUNDS

Overall U.S. magnesium compounds production decreased in 1989, although caustic-calcined magnesia production increased. Imports continued to supply a significant share of U.S. demand, but the dramatic annual increases in imports that occurred in the mid-1980's appeared to have stabilized.

Refractories were the principal use for dead-burned magnesia, and caustic-calcined magnesia was used primarily in

TABLE 8

MAGNESIUM: WORLD PRIMARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Brazil	2,615	4,356	5,488	5,865	6,200
Canada[e]	7,200	5,100	8,800	7,600	7,200
China[e]	[r]3,000	[r]3,000	[r]3,000	[r]3,200	3,200
France	13,639	13,361	13,601	13,800	13,900
Italy	7,863	[r]12,417	7,626	5,436	[2]2,770
Japan	8,456	8,116	8,180	9,012	[2]11,385
Norway	54,704	56,522	56,907	50,300	[2]49,827
U.S.S.R.[e]	87,000	89,000	90,000	91,000	91,000
United States	135,728	125,639	124,396	141,983	[2]152,066
Yugoslavia	4,978	4,897	5,932	6,176	6,000
Total	[r]325,183	[r]322,408	323,930	334,372	343,548

[e] Estimated. [p] Preliminary. [r] Revised.
[1] Table includes data available through June 22, 1990.
[2] Reported figure.

TABLE 9

MAGNESIUM: WORLD SECONDARY PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Brazil	2,006	1,767	1,376	[e]1,500	1,500
Japan	20,894	14,415	10,284	10,020	12,000
U.S.S.R.[e]	8,000	8,000	8,000	8,000	8,000
United Kingdom[e]	900	1,000	1,000	1,000	1,000
United States	41,298	41,807	45,165	50,207	[2]51,200
Total	73,098	66,989	65,825	70,727	73,700

[e] Estimated. [p] Preliminary.
[1] Table includes data available through June 22, 1990.
[2] Reported figure.

animal feed and chemicals. Seawater and brines were the main raw materials for magnesium compound production, accounting for more than 60%, with dolomite, magnesite, and olivine as the other source materials.

Many world producers of magnesia were upgrading their facilities to produce higher grade materials rather than increasing their capacity. Demand from the refractories users, such as the iron and steel industry, for better-quality, longer-lasting refractories resulted in this shift from higher quantity to higher quality.

Production

Caustic-calcined magnesia production increased for the third year in a row, and dead-burned magnesia production declined, reversing a 2-year trend. Production of olivine declined by 9%, and average value decreased by 16%.

Early in 1989, a partnership formed between managers of Merck & Co. Inc.'s magnesium chemicals business and C. P. Hall Co. purchased the assets of Merck's magnesium chemicals business. Although Merck sold the San Francisco, CA, plant to Genentech Inc. in 1988, the partnership, named Marine Magnesium Co., negotiated an open-ended lease with Genentech to continue operations at the plant for at least 3 years. C. P. Hall, a purchaser and reseller of specialty magnesias, was expected to continue to be Marine Magnesium's largest customer. National Refractories & Minerals Corp. announced in July that it completed an expansion of capacity for production of 50% magnesium hydroxide slurry. This expansion would triple magnesium hydroxide slurry capacity at its Moss Landing, CA, seawater plant to 400,000 tons per year.

Consumption and Uses

Refractories for use in iron and steel, nonferrous metals, glass, and cement production facilities were the dominant use for dead-burned magnesia. Caustic-calcined magnesia was used in a wide variety of applications. Animal feed, representing 27% of U.S. caustic-calcined magnesia shipments, was the largest consuming industry. Chemical uses accounted for 24% of domestic shipments. The following uses, in declining order, accounted for 24% of caustic calcined magnesia shipments: rayon manufacture, refractories, fertilizer, and fuel additive. The remaining 25% of domestic shipments was consumed by the following industries, in declining order: stack-gas scrubbing, rubber, electrical, water treatment, ceramics, medicine and pharmaceuticals, oxychloride and oxysulfate cements, sugar, pulp and paper, uranium processing, insulation and wallboard, candies, foundry, and winemaking.

Magnesium carbonate and magnesium sulfate were used principally in the pharmaceutical industry, with smaller use for chemicals and fertilizers. Magnesium carbonate also was used in the rubber industry, and magnesium sulfate was used for animal feed. Magnesium chloride brines were used primarily in chemical applications, with smaller uses in ceramics and dust control. Pulp and paper was the main consuming industry for magnesium hydroxide. Smaller quantities were used in the chemical and water

TABLE 10

SALIENT MAGNESIUM COMPOUND STATISTICS

(Thousand metric tons and thousand dollars)

	1985	1986	1987	1988	1989
United States:					
Caustic-calcined and specified magnesias:[1]					
Shipped by producers:[2]					
Quantity	91	86	103	124	135
Value	$33,772	$33,969	$27,565	$36,500	$39,529
Exports, value[3]	$9,773	$13,295	$14,167	$13,322	$2,263
Imports for consumption, value[3]	$10,407	$11,493	$4,575	$2,371	$13,657
Refractory magnesia:					
Shipped by producers:[2]					
Quantity	263	249	296	371	348
Value	$81,149	$73,172	$80,760	$103,400	$97,673
Exports, value	$5,529	$5,488	$3,240	$9,262	$10,685
Imports for consumption, value	$29,767	$36,718	$41,333	$42,885	$38,555
Dead-burned dolomite:					
Sold and used by producers:					
Quantity	341	385	259	748	533
Value	$24,454	$27,789	$21,766	$45,256	$38,208
World production (magnesite)	r12,168	r12,299	11,753	p11,936	e12,003

e Estimated. p Preliminary. r Revised.

[1] Excludes caustic-calcined magnesia used in the production of refractory magnesia.

[2] Includes magnesia used by producers.

[3] Caustic-calcined magnesia only.

TABLE 11

U.S. MAGNESIUM COMPOUNDS SHIPPED AND USED

	1988		1989	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
Caustic-calcined[1] and specified (USP and technical) magnesias	123,905	$36,500	134,641	$39,529
Magnesium hydroxide [100% $Mg(OH)_2$][1]	392,743	76,031	341,933	70,260
Magnesium sulfate (anhydrous and hydrous)	61,505	19,185	63,432	19,819
Precipitated magnesium carbonate[1]	2,877	655	2,332	641
Refractory magnesia	371,296	103,400	348,316	97,673

[1] Excludes material produced as an intermediate step in the manufacture of other magnesium compounds.

treatment industries. Magnesium chloride was used for chemicals and oxychloride and oxysulfate cements.

The bulk of U.S. olivine shipments, 68%, was used as foundry sands. Refractories represented 18% of olivine shipments, and the remaining 14% was used for slag control, soil conditioning, and unspecified applications.

Prices

Yearend magnesium compound prices, published in the Chemical Marketing Reporter, have remained unchanged since 1987. Yearend prices were as follows:

Magnesia, natural, technical, heavy, 85%, f.o.b. Nevada	per short ton	$232
Magnesia, natural, technical, heavy, 90%, f.o.b. Nevada	do.	265
Magnesium chloride, hydrous, 99% flake	do.	290
Magnesium carbonate, light, technical (freight equalized)	per pound	$0.73–.78
Magnesium hydroxide, National Formulary, powder (freight equalized)	do.	.78
Magnesium sulfate, technical	do.	.14

Foreign Trade

Because of the implementation of the HTS beginning in 1989, trade data for 1989 are not comparable with those of the previous years. For magnesium compounds, additional data on exports of crude magnesite and various magnesium compounds were separated that were previously included in categories containing other materials.

Trade data for olivine were combined with other trade data by the Bureau of the Census and could not be separately identified. According to the Journal of Commerce Port Import/Export Reporting Service, 205,090 tons of olivine was imported from Norway, and the United States exported 4,491 tons, mainly to Chile and Peru.

World Review

Australia.—After completing a feasibility study in June, the joint-venture partners in the Queensland Magnesia Project planned to begin construction of a magnesia plant by yearend. The new plant, in Kunwarara, was expected to have an annual capacity of 150,000 tons of dead-burned magnesia and 25,000 tons of fused magnesia. Initial production was planned for mid-1991, with product shipments beginning in September. The magnesite deposit that will serve as the feed for the plant was estimated to contain 400 million tons of magnesite. Two areas, designated KG1 and KG2 and representing 13% of the total deposit, were targeted for initial mining operations at a rate of between 1.75 and 2 million tons per year.

Brazil.—Magnesita S.A., the largest magnesite producer in the country, also produces refractory brick and planned to install a new shaft kiln, with a capacity of 50,000 tons of brick per year at its plant in Minas Gerais. The new kiln,

TABLE 12

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989 Quantity (metric tons)	1989 Value (thousands)
Caustic-calcined magnesia:		
Canada	2,228	$1,022
Germany, Federal Republic of	199	128
Mexico	871	306
Netherlands	858	536
Other	219	271
Total	4,375	2,263
Dead-burned and fused magnesia:		
Australia	1,027	316
Belgium	417	138
Canada	11,574	5,960
France	2,626	676
Korea, Republic of	482	249
Mexico	5,357	2,804
Taiwan	585	298
Venezuela	206	59
Other	251	185
Total	22,525	10,685
Other magnesia:		
Australia	311	456
Brazil	102	91
Canada	505	282
Colombia	180	309
France	187	77
Germany, Federal Republic of	2,273	1,206
Israel	1,942	643
Italy	190	63
Mexico	548	747
Panama	116	11
Spain	2,023	1,016
Sweden	302	100
Taiwan	159	103
Thailand	123	63
United Kingdom	141	84
Venezuela	6,319	2,743
Other	422	1,219
Total	15,843	9,213
Natural magnesite:		
Australia	124	117
Belgium	185	331
Brazil	394	906
Canada	1,365	668
Germany, Federal Republic of	433	542

TABLE 12—Continued

U.S. EXPORTS OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989 Quantity (metric tons)	1989 Value (thousands)
Natural magnesite—Continued		
Greece	180	$226
Italy	1,214	1,119
Korea, Republic of	215	109
Mexico	4,583	2,757
Netherlands	217	277
Romania	165	98
Spain	468	389
Taiwan	255	194
Other	582	566
Total	10,380	8,299
Calcined dolomite:		
Canada	22,109	6,323
Colombia	1,046	185
Mexico	9,330	1,977
Peru	1,500	476
Spain	2,000	659
Trinidad	956	163
Venezuela	2,500	847
Other	198	53
Total	39,639	10,683

Source: Bureau of the Census.

TABLE 13

U.S. EXPORTS OF MAGNESIUM COMPOUNDS

Year	Magnesium hydroxide and peroxide		Magnesium chloride (anhydrous and other)		Magnesium sulfate (natural kieserite and epsom salts)		Magnesium sulfate (other)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989	12,072	$3,673	2,201	$1,812	95	$96	483	$519

Source: Bureau of the Census.

expected to be operational by 1991, was designed to produce a high-density, 98% magnesia brick. In addition, one of Magnesita's subsidiaries, Refratec-Productos Electrofundidos Ltd., planned to construct a 2,400-ton-per-year plant to produce a high-temperature grade of fused magnesia. Both of these new operations were part of Magnesita's program to develop new refractory products for basic-oxygen furnaces and electric arc furnaces.[10]

Canada.—Baymag officially opened a 14,000-ton-per-year fused magnesia plant in September in Exshaw, Alberta. Baymag produced caustic-calcined magnesia at its nearby plant as the raw material for the fused magnesia plant. To maintain feedstock supply, Baymag announced that it would construct a 50,000-ton-per-year facility for caustic-calcined magnesia at the new plant site. Because of the high degree of automation in the new plant, the entire operation reportedly could be run by six people. Depending on market strength, Baymag planned to double the plant's capacity by adding two electric arc furnaces.[11] In addition to its production of fused and caustic-calcined magnesia, Baymag was expected to supply magnesite for a new magnesium metal plant scheduled to begin operation in 1990.

India.—Tamilnadu Magnesite Products Ltd. reportedly was constructing a

TABLE 14

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989	
	Quantity (metric tons)	Value (thousands)
Caustic-calcined magnesia:		
Canada	56,069	$10,996
China	7,569	808
Greece	6,456	789
Mexico	3,203	416
Turkey	2,108	534
Other	179	114
Total	75,584	13,657
Dead-burned and fused magnesia:		
Canada	9,746	4,582
China	61,382	4,914
Czechoslovakia	12,159	948
Greece	45,346	7,800
Hong Kong	4,230	414
Ireland	13,551	4,467
Israel	1,122	404
Japan	11,384	2,955
Mexico	25,050	7,832
Netherlands	3,186	1,056
United Kingdom	15,484	3,107
Other	150	76
Total	202,790	38,555
Other magnesia:		
Canada	390	123
Germany, Federal Republic of	60	86

TABLE 14—Continued

U.S. IMPORTS FOR CONSUMPTION OF CRUDE AND PROCESSED MAGNESITE, BY COUNTRY

Country	1989	
	Quantity (metric tons)	Value (thousands)
Other magnesia—Continued		
Japan	4,226	$7,591
Mexico	335	156
United Kingdom	370	394
Other	493	844
Total	5,874	9,194
Crude magnesite:		
Canada	1,077	225
China	6,344	645
France	158	66
Germany, Federal Republic of	55	8
India	5	3
Italy	259	127
Japan	424	250
Mexico	21	8
Taiwan	1	10
United Kingdom	28	12
Total	8,372	1,354
Calcined dolomite:		
Canada	20,854	2,755
Germany, Federal Republic of	194	41
Ireland	10	4
Mexico	730	71
Total	21,788	2,871

Source: Bureau of the Census.

TABLE 15

U.S. IMPORTS FOR CONSUMPTION OF MAGNESIUM COMPOUNDS

Year	Magnesium hydroxide and peroxide		Magnesium chloride (anhydrous and other)		Magnesium sulfate (natural kieserite)		Magnesium sulfate (natural epsom salts)		Magnesium sulfate (other)	
	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)	Quantity (metric tons)	Value (thousands)
1989	1,792	$3,091	5,994	$1,202	11,781	$540	166	$33	9,269	$2,076

Source: Bureau of the Census.

30,000-ton-per-year plant to produce dead-burned magnesia. The new plant, scheduled to come on-stream in 1991, will use technology patented by Sulzer Brothers Ltd. of the Federal Republic of Germany to beneficiate low-grade magnesite to dead-burned magnesite containing greater than 99% magnesia. High-grade magnesia produced at the plant was expected to be used for refractory bricks in the country's growing steel industry. Tamilnadu Magnesite also produced caustic-calcined magnesia for export.

South Africa, Republic of.—Chamotte Holdings (Pty.) Ltd. installed kilns to produce caustic-calcined magnesia for use in animal feed and fertilizers at its operation in Malelane. The company has produced refractory magnesia, and installation of the new kilns was expected to reduce the Republic of South Africa's import dependence on caustic-calcined magnesia. Chamotte Holdings also completed a 6,000-ton-per-year magnesium sulfate plant, with the output destined primarily for paper, agricultural, and other smaller markets. A third project involved the installation of a plant to produce 75,000 tons per year of magnesium carbonate fines.

Outlook

Because the largest use for magnesium compounds is in the manufacture of refractories, this industry segment has had the greatest influence on overall magnesium compounds demand. Following the contraction of the iron and steel industry in the mid-1980's, magnesia refractories demand declined to historic lows. However, a combination of retrenchment and processing changes in the iron and steel industry led to stronger demand for magnesia refractories in the latter part of the 1980's. Growth for magnesia refractories in the early 1990's was expected to continue, but at a slower pace than in the late 1980's. Changes in steel furnace technology led to the substitution of magnesia refractories in place of other types of refractories. But at the same time, development of longer-lived magnesia refractories lengthened the amount of time between furnace relinings.

Although total demand for magnesium compounds has increased significantly from its low point in the mid-1980's, magnesia production in the United States has not increased as significantly. When the industry was depressed, cheaper imports of magnesia, particularly from China and Greece, began to increase dramatically. Import reliance for magnesium compounds rose from 4% in 1982 to 25% in 1985 and has remained above 20% since then. Even though import reliance has leveled off somewhat, the United States was expected to continue to rely on imported material to supply about 20% of domestic magnesium compounds demand.

TABLE 16

WORLD MAGNESIUM COMPOUNDS ANNUAL PRODUCTION CAPACITY,[1] DECEMBER 31, 1989

(Thousand metric tons, MgO equivalent)

Country	Raw material	
	Magnesite	Seawater or brines
North America:		
Canada	160	—
Mexico	—	170
United States	100	913
Total	260	1,083
South America: Brazil	345	—
Europe:		
Austria	576	—
Czechoslovakia	700	—
France	—	30
Greece	612	—
Ireland	—	100
Italy	—	125
Netherlands	—	120
Norway	—	25
Poland	10	—
Spain	205	—
Turkey	285	—
U.S.S.R.	2,100	100
Yugoslavia	240	—
Total	4,728	500
Africa:		
Kenya	170	—
South Africa, Republic of	84	—
Zimbabwe	2	—
Total	256	—
Asia:		
China	1,000	10
India	229	—
Israel	—	70
Japan	—	485
Korea, North	1,250	—
Korea, Republic of	—	50
Nepal	125	—
Total	2,604	615
Oceania: Australia	10	—
Grand total	8,203	2,198

[1]Includes capacity at operating plants as well as at plants on standby basis.

BACKGROUND

Definitions, Grades, and Specifications

Primary magnesium metal contains a minimum of 99.8% magnesium. Magnesium-base alloys are named by the composition of the two chief alloying elements, each designated by a letter, and the approximate percentage of each alloying element. For example, AZ91 contains about 9% aluminum (A) and 1% zinc (Z), and HK31 contains about 3% thorium (H) and 1% zirconium (K). Other letters used to specify magnesium alloys are E for rare-earth metals and M for manganese.

Although many minerals contain magnesium magnesite, dolomite, brucite, and olivine are the only minerals from which magnesium is recovered commercially. Magnesite, or magnesium carbonate ($MgCO_3$), has a theoretical magnesia content of 47.6%. Dolomite is a calcium carbonate-magnesium carbonate mineral ($CaCO_3 \cdot MgCO_3$) that has a theoretical magnesia content of 22%. Brucite, magnesium hydroxide [$Mg(OH)_2$] contains up to 69% magnesia, and olivine ($Mg_2Fe_2SiO_4$) contains up to 19% magnesium. Of these minerals, magnesite and dolomite are the largest sources of magnesium.

Seawater, brines, and bitterns represent vast sources of magnesium and magnesium compounds. In the United States, more than 60% of the magnesium compounds produced annually are recovered from seawater and brines, and 78% of the magnesium metal production capacity uses seawater or brines as a raw material.

Various magnesia products are made by calcining magnesium carbonate or

TABLE 17

MAGNESITE: WORLD PRODUCTION, BY COUNTRY[1]

(Metric tons)

Country	1985	1986	1987	1988[p]	1989[e]
Australia	57,535	41,441	53,941	56,446	55,000
Austria	1,255,043	1,084,360	946,943	1,121,585	1,200,000
Brazil[2]	r260,754	r296,792	390,182	404,000	400,000
Canada[e 3]	136,000	144,000	150,000	150,000	150,000
China[e]	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
Colombia	14,230	14,936	r15,000	r15,000	15,000
Czechoslovakia	654,000	666,000	671,000	630,786	600,000
Greece	845,888	884,373	841,000	930,000	900,000
India	417,412	422,000	430,000	460,000	465,000
Iran[e 4]	5,000	5,000	5,000	5,000	5,000
Kenya[e]	300,000	300,000	(5 6)	(5 6)	—
Korea, North[e]	1,900,000	1,900,000	1,900,000	1,900,000	1,900,000
Mexico	19,299	7,530	7,351	7,531	7,500
Nepal	19,851	63,190	38,388	45,000	40,000
Pakistan	2,113	1,757	3,740	3,081	3,000
Philippines[e]	r676	650	650	650	700
Poland	19,200	20,900	22,300	23,000	23,000
South Africa, Republic of	28,898	61,186	74,961	74,088	74,000
Spain[e]	r692,196	700,000	710,000	710,000	720,000
Turkey	1,128,961	1,313,763	1,185,904	1,161,416	1,200,000
U.S.S.R.[e]	1,975,000	1,925,000	r1,875,000	r1,825,000	1,825,000
United States	W	W	W	W	W
Yugoslavia	417,000	423,000	403,000	383,000	390,000
Zimbabwe	19,385	22,649	28,991	30,121	30,000
Total	r12,168,441	r12,298,527	11,753,351	11,935,704	12,003,200

[e] Estimated. [p] Preliminary. [r] Revised. W Withheld to avoid disclosing company proprietary data; not included in "Total."

[1] Figures represent crude salable magnesite. In addition to the countries listed, Bulgaria produced magnesite, but output is not reported quantitatively, and available general information is inadequate for formulation of reliable estimates of output levels. Table includes data available through May 2, 1990.

[2] Series reflects output of marketable concentrates. Production of crude ore was as follows, in metric tons: 1985—623,330; 1986—648,752; 1987—860,163; 1988—810,837; and 1989—850,000 (estimated).

[3] Magnesitic dolomite and brucite. Figures are estimated on the basis of reported tonnage dollar value.

[4] Year beginning Mar. 21 of that stated.

[5] Reported figure.

[6] Revised to zero.

magnesium hydroxide at different temperatures. Caustic-calcined magnesia, which is readily reactive with water, is calcined at temperatures up to 890° C. Dead-burned magnesia, also called refractory or sintered magnesia, is calcined at temperatures up to 1,450° C and is unreactive with water. Fused magnesia is produced at temperatures greater than 3,000° C. Magnesia produced from magnesite is generally called natural magnesia, and magnesia recovered from seawater or brines is called synthetic magnesia.

Standards for magnesia generally are set by the consumer for a specific application. Refractory magnesia composition depends on the area of the furnace in which the material is to be used. Magnesia produced from magnesite can contain between 88% and 98% magnesia, with varying quantities of silica, iron, calcium, and alumina impurities. Synthetic magnesia normally is purer than natural magnesia, containing between 92% and 99.5% magnesia, with smaller quantities of the same impurities found in natural magnesia. Most fused magnesia contains greater than 94% magnesia.

Products for Trade and Industry

The principal use for magnesium metal, averaging greater then 50% of domestic consumption annually, is as an alloying addition to aluminum. Magnesium improves the hardness and corrosion resistance of pure aluminum. Aluminum-magnesium alloys are used in a wide variety of applications, including automobiles, trucks, aircraft, appliances, and home siding. Two-piece beverage cans, each containing about 2% magnesium, are the largest single use for these aluminum-magnesium alloys.

Magnesium and its alloys are used as structural components in automobiles, trucks, aircraft, computers, and power tools. Many of these applications use magnesium because of its light weight and its ease of machinability. Magnesium is used in the iron and steel industry for external hot-metal desulfurization and in the production of nodular iron. Production of the nonferrous metals beryllium, hafnium, titanium, uranium, and zirconium involves the

use of magnesium as a reducing agent. Anodes of magnesium are used for cathodic protection of iron and steel in underground pipe and water tanks. Small quantities of magnesium are used as a catalyst in producing organic compounds, as photoengraving plates, and in alloys other than aluminum.

Refractory magnesia represents the largest use of magnesium in compounds. Refractory magnesia is manufactured into bricks and other lining materials principally for use in the furnaces and auxiliary equipment used to produce iron and steel. Magnesia-base refractories also are used in furnaces in the cement, glass, and nonferrous metals industries.

Caustic-calcined magnesia is used in a myriad of applications in the agriculture, chemical, construction, and manufacturing industries. Caustic-calcined magnesia is an important component of animal feed and fertilizer, providing essential nutrients for livestock and plant growth. In construction, caustic-calcined magnesia is used in special cements for industrial flooring and in lightweight insulating wallboard. In the chemical industry, it is used as a starting point for the manufacture of other magnesium salts. Special grades of caustic-calcined magnesia are used for pharmaceuticals, including antacids, toothpaste, milk of magnesia, and cosmetics. Magnesia is used to remove sulfur from flue gases and boiler fuels and is used for acid neutralization in process wastewater and in lubricating oils. Caustic-calcined magnesia also is important in manufacturing paper, rayon, and rubber.[12]

Other magnesium compounds are used in place of, or in addition to, caustic-calcined magnesia in many of the above applications. Magnesium hydroxide is used in the pulp and paper industry; magnesium sulfate is used for pharmaceuticals, animal feed, and fertilizers; and magnesium carbonate is used in the chemical, pharmaceutical, and rubber industry. Fused magnesia is mainly used for electrical insulation.

The principal use for olivine is as a foundry sand used in casting iron and steel components and some nonferrous metals. Olivine is used in smaller quantities for refractories, slag control in blast furnaces, and soil conditioning. In Europe, olivine is used instead of sand for blasting debris from buildings and bridges and in incinerators.[13]

Industry Structure

U.S. producers of primary magnesium and magnesium compounds are shown in tables 18 and 19. Olivine is produced by two companies in the United States—Applied Industrial Minerals Corp. (AIMCOR) and Olivine Corp. AIMCOR operates two mines and processing plants in Indiana, North Carolina, and Washington. Olivine operates one mine and one processing plant in Washington.

Norway, the U.S.S.R., and the United States, with large electrolytic plants, represent 82% of the world's magnesium metal production capacity. Smaller thermal plants are located in Canada, China, France, Italy, Japan, and Yugoslavia. Canada is expected to replace Norway as the third largest producer in 1990 when two new electrolytic facilities come on-stream.

In the rest of the world, the largest magnesite production facilities are located in the centrally planned economies of China, North Korea, and the U.S.S.R. Together, these three countries account for 53% of the world's magnesite production capacity. Japan and the United States account for nearly 64% of the capacity for magnesium compounds production from seawater and brines. Fused magnesia is produced in France, Israel, Japan, the United Kingdom, and the United States.

Norway is the world's largest producer of olivine, and, in addition to supplying domestic needs, Norway's production is exported throughout the world. Countries with smaller output are Austria, Italy, Japan, Mexico, Spain, and the United States.

Technology

Two thermal processes currently are in use to recover magnesium metal

TABLE 18

U.S. MAGNESIUM METAL PRODUCERS, BY LOCATION, RAW MATERIAL, AND PRODUCTION CAPACITY IN 1989

Company	Plant location	Raw material	Annual capacity (metric tons)
The Dow Chemical Co.	Freeport, TX	Seawater	90,000
Magnesium Corp. of America	Rowley, UT	Lake brines	35,000
Northwest Alloys Inc.	Addy, WA	Dolomite	35,000
Total			160,000

TABLE 19

U.S. MAGNESIUM COMPOUND PRODUCERS, BY RAW MATERIAL SOURCE, LOCATION, AND PRODUCTION CAPACITY IN 1989

Raw material source and producing company	Location	Capacity (metric tons of MgO equivalent)
Magnesite: Basic Inc.	Gabbs, NV	100,000
Lake brines:		
Great Salt Lake Minerals & Chemicals Corp.	Ogden, UT	90,000
Reilly Industries Inc.	Wendover, UT	45,000
Well brines:		
The Dow Chemical Co.	Ludington, MI	200,000
Martin Marietta Chemicals	Manistee, MI	300,000
Morton Chemical Co.	do.	10,000
Seawater:		
Barcroft Co.	Lewes, DE	5,000
Basic Magnesia Inc.	Port St. Joe, FL	50,000
The Dow Chemical Co.	Freeport, TX	68,000
Marine Magnesium Co.	South San Francisco, CA	15,000
National Refractories & Minerals Corp.	Moss Landing, CA	130,000
Total		1,013,000

from dolomite—the Pidgeon process and the Magnetherm process. Both utilize the same basic chemistry, but the Pidgeon process uses an external heat source, and the Magnetherm process uses heat generated by the electrical resistance of the reactants. In the Pidgeon process, dolomite and ferrosilicon are formed into briquettes and heated in a retort under a vacuum. Magnesium oxide in the dolomite reacts with the silicon to produce magnesium vapor, which is cooled and condensed in a separate section of the retort. Plants in Canada, Italy, and Japan use this process to recover magnesium.

In the Magnetherm process, calcined dolomite, ferrosilicon, and alumina are heated under a vacuum. Alumina reduces the melting point of the slag produced by the dolomite-ferrosilicon reaction to make resistance heating practical. Magnesium vapor is cooled and condensed in a condensing chamber. The Magnetherm process is used by plants in Brazil, France, Japan, the United States, and Yugoslavia.

Electrolytic recovery of magnesium requires a magnesium chloride feedstock that is prepared from seawater or brines. Two types of magnesium chloride can be prepared—hydrous and anhydrous. In the preparation of hydrous magnesium chloride, used by Dow, magnesium hydroxide is precipitated from seawater by the addition of dolomitic limestone. Adding hydrochloric acid to the magnesium hydroxide produces a neutralized magnesium chloride solution. This solution is dehydrated until it contains about 25% water and fed directly to electrolytic cells.

MagCorp and Norsk Hydro use an anhydrous magnesium chloride feed for their electrolytic cells. MagCorp uses solar evaporation initially to concentrate magnesium chloride brines from the Great Salt Lake. After adding calcium chloride to precipitate sulfate impurities, the brine is further concentrated and dehydrated in a spray dryer. The resulting powder is melted and purified to yield an anhydrous material. Norsk Hydro starts with concentrated magnesium chloride brine. The brine is purified, concentrated, prilled, and dehydrated to produce anhydrous magnesium chloride.

Electrolytic cells used to recover magnesium from either hydrous or anhydrous magnesium chloride differ from company to company, and most information about cell design and operating conditions are usually not disclosed. Essentially, magnesium chloride fed to an electrolytic cell is broken down into magnesium metal and chlorine gas by direct current at 700° C. Magnesium is removed from the cell and cast into ingots, and the chlorine gas is collected and recycled or sold.[14]

Mineral Process Licensing Corp. developed a one-step process for producing anhydrous magnesium chloride from magnesite that was expected to be used in the MagCan plant in Canada. Reacting magnesite with chlorine gas in the presence of carbon monoxide in a packed-bed reactor at 900° C produces magnesium chloride and carbon dioxide. Liquid magnesium chloride collects at the bottom of the reactor and is tapped periodically for transfer to the electrolytic cells.[15]

Preparing either caustic-calcined or dead-burned magnesia from magnesite involves crushing the magnesite to various sizes, depending on the type of material to be produced. After crushing, magnesite is beneficiated; the degree of beneficiation depends on the quality of the ore and the end use. Lower quality ore often requires heavy-media separation, magnetic separation, and flotation to remove impurities. High-quality ore may require only screening and hand sorting to produce a material of acceptable quality. Caustic-calcined magnesia is produced in shaft kilns, multiple-hearth furnaces, or rotary kilns. Dead-burned magnesia is produced in rotary kilns.

In producing synthetic magnesia, seawater or brines are treated either with a small quantity of lime or sulfuric

TABLE 20

U.S. IMPORT DUTIES

Item	HTS No.	Most favored nation (MFN) Jan. 1, 1989	Non-MFN Jan. 1, 1989
Magnesium:			
Unwrought magnesium	8104.11.0000	8.0% ad val.	100% ad val.
Unwrought magnesium alloys	8104.19.0000	6.5% ad val.	60.5% ad val.
Wrought magnesium	8104.90.0000	14.8¢/kg on Mg content + 3.5% ad val.	88¢/kg on Mg content + 20.0% ad val.
Magnesium waste and scrap	8104.20.0000	Free	Free.
Magnesium compounds:			
Crude magnesite	2519.10.0000	Free	$10.33/ton.
Dead-burned and fused magnesia	2519.90.1000	0.4¢/kg	1.7¢/kg.
Caustic-calcined magnesia	2519.90.2000	$2.07/ton	$20.70/ton.
Magnesia, other	2519.90.5000	Free	15.4¢/kg.
Calcined dolomite	2518.20.0000	6% ad val.	30% ad val.
Kieserite, natural	2530.20.1000	Free	Free.
Epsom salts, natural	2530.20.2000	3.7% ad val.	20% ad val.
Magnesium hydroxide and peroxide	2816.10.0000	3.1% ad val.	25% ad val.
Magnesium chloride	2827.31.0000	1.5% ad val.	5% ad val.
Magnesium sulfate	2833.21.0000	3.7% ad val.	20% ad val.

acid to remove dissolved carbon dioxide. Then calcium hydroxide, in the form of lime or dolime, is added to precipitate the dissolved magnesium as magnesium hydroxide. The resulting slurry is thickened and vacuum-filtered to yield a filter cake containing about 50% magnesium hydroxide. The filter cake can be directly calcined to produce caustic-calcined or dead-burned magnesia, or it can be calcined and pelletized before dead-burning to give specific size and density characteristics.

Fused magnesia is produced by fusion of high-grade magnesite or caustic-calcined synthetic magnesia in an electric arc furnace. After fusion, the material is crushed, inspected to remove any unfused magnesia, and crushed further in a ball mill.

Economic Factors

Costs to produce magnesium metal vary greatly, depending upon the feed material and the process used. Operating costs for magnesium production range from $309 to $2,283 per ton, with energy costs as the largest component of the total operating cost. Total production costs from seawater sources were lower than from brines or dolomite sources. Magnesium compound operating costs also vary depending upon source material and processing techniques. Operating costs range from $24 to $425 per ton for magnesium compound production, with seawater as the most costly source. Energy costs also represent the largest component of operating costs.[16]

Tariffs for magnesium and magnesium compounds are shown in table 20. Depletion allowance for magnesium chloride from domestic or foreign sources is 5%. Magnesium carbonate and dolomite have depletion allowances of 14% from domestic and foreign ores. Depletion allowances for other ores are brucite, 10% (domestic and foreign); and olivine, 22% (domestic) and 14% (foreign).

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TABLE 21

MAGNESIUM SUPPLY-DEMAND RELATIONSHIPS

(Thousand metric tons of contained magnesium)

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
WORLD PRODUCTION											
United States:											
Nonmetal	909	727	690	512	567	574	420	412	464	622	544
Metal	[1]147	[1]153	140	93	104	144	136	125	124	142	152
Total	1,056	880	830	605	671	718	556	537	588	764	696
Rest of world:											
Nonmetal	4,558	4,726	4,668	4,371	4,777	4,676	4,807	4,845	4,688	[p]4,790	[e]4,760
Metal	160	162	169	161	156	184	189	196	200	[p]192	[e]192
Total	4,718	4,888	4,837	4,532	4,933	4,860	4,996	5,041	4,888	[p]4,982	[e]4,952
World total	5,774	5,768	5,667	5,137	5,604	5,578	5,552	5,578	5,476	[p]5,746	[e]5,648
COMPONENTS AND DISTRIBUTION OF U.S. SUPPLY											
U.S. production:											
Nonmetal	909	727	690	512	567	574	420	412	464	622	544
Primary metal	147	153	140	93	104	144	136	125	124	142	152
Secondary metal (old scrap)	13	16	22	21	23	24	24	23	23	28	28
Imports:											
Nonmetal	54	46	50	39	61	115	134	160	164	198	171
Metal	5	4	6	5	5	9	8	8	11	14	12
Industry stocks, metal, Jan. 1	45	40	44	57	42	25	32	39	39	28	25
Total U.S. supply	1,173	986	952	727	802	891	754	767	825	1,032	932
Distribution of U.S. supply:											
Exports:											
Nonmetal	55	59	32	20	15	27	25	25	20	34	26
Metal	49	52	32	36	43	44	36	40	44	50	57
Industry stocks, metal, Dec. 31	40	44	57	42	25	32	39	39	28	25	26
Industrial demand[2]	1,029	831	831	629	719	788	654	663	733	923	823
U.S. DEMAND PATTERN											
Nonmetal:											
Refractories	817	629	609	446	508	531	402	376	453	583	484
Chemicals	91	85	99	85	105	131	127	171	155	203	205
Total	908	714	708	531	613	662	529	547	608	786	689
Metal:											
Cans and containers	17	19	20	17	19	23	23	22	39	39	42
Transportation	40	36	38	25	31	36	38	33	38	38	36
Machinery	35	34	34	33	34	29	22	27	19	20	17
Chemicals	10	7	8	6	7	8	5	3	2	1	1
Nonferrous metal production	8	10	13	7	6	9	12	9	5	11	12
Iron and steel foundries	5	5	5	4	3	4	3	3	2	3	2
Other[3]	6	6	5	6	6	17	22	19	20	25	24
Total	121	117	123	98	106	126	125	116	125	137	134
Total industrial demand	1,029	831	831	629	719	788	654	663	733	923	823
Total U.S. primary demand[4]	1,016	815	809	608	696	764	630	640	710	895	795
Total U.S. demand for primary metal[5]	108	101	101	77	83	102	101	93	102	109	106

[e] Estimated. [p] Preliminary.

[1] Derived from production data published by the International Magnesium Association and the Canadian Department of Energy, Mines and Resources.

[2] Sum of total nonmetal and total metal demands.

[3] Includes iron and steel desulfurization from 1984 to 1989.

[4] Total U.S. demand less U.S. recovery from secondary metal.

[5] U.S. demand for metal less U.S. recovery from secondary metal.